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Integrating robotics into Moncton's waste management system: a smart sustainable city approach

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ABSTRACT

Rapid urbanization and population growth continue to pose significant challenges for effective solid waste management worldwide. Moncton, New Brunswick, exemplifies a mid-sized Canadian city struggling with inefficiencies in its waste collection system despite the adoption of a three-stream approach. This study explores how robotic automation, particularly collaborative robots (cobots) powered by artificial intelligence (AI), can enhance Moncton's waste sorting processes. Guided by the PRISMA framework and employing a qualitative case study methodology, the research identifies stages within Moncton's waste infrastructure that are most suitable for robotic integration. The objectives of the study are threefold: to evaluate the feasibility of robotic sorting, to assess its contribution to Moncton's sustainability targets, and to propose a framework for integration within a smart city model. Findings indicate that robotic waste sorting can significantly improve accuracy, reduce contamination, and optimize labor use. Furthermore, local innovation partnerships have the potential to lower costs and generate new employment opportunities. The study concludes that robotic automation aligns with Moncton's Community Energy and Emissions Plan (CEEP) and supports Canada's 2030 Sustainable Development Goals. It provides a scalable and sustainable model that can be replicated by other mid-sized cities facing similar waste management challenges.

KEYWORDS: Robotic waste sorting. Collaborative robots. Artificial intelligence. Smart city. Waste management.

INTRODUCTION

The introduction of new technology and an ever-increasing population in major cities around the world makes the need to seek more transformative and innovative ways to improve the quality of life, especially for people living in major cities, a great priority. One of the most obvious challenges that modern urbanization presents to us is the need to find effective ways and measures to dispose of waste, as well as to develop effective strategies for addressing the disposal of solid waste, which affects not only the quality of the air we breathe but also the overall climatic conditions (Harrison & Donnelly, 2011; Carli et al., 2013). Discovering more effective and efficient methods of sorting waste is crucial in helping industries that deal with recycling waste while also reducing the need for landfilling and decreasing environmental pollutants. Despite this, many cities and clustered populations continue to manage waste by relying on manual and outdated methods that require more hands and are prone to human errors, thereby limiting developmental efforts in establishing an effective waste management system in the long run (Kamczyc, 2021).

A good example is seen in Moncton, New Brunswick, where the need for effective waste management in a populated region is of great concern. The residents of such places are always advised to separate their waste into three different bin bags or cans, as the case may be; one bag will carry compostables, the second will carry recyclables, and the third will be for general waste (City of Moncton, 2025). Despite this, there has been little or no cooperation from the residents in sorting these wastes when disposing of them, which indicates that public participation is often not reliable while the need for a reduced labor force in the collection and sorting of waste continues to linger (Kamczyc, 2021). These are major indicators that suggest there is an emergent need to improve and find more effective methods in combating waste management, thereby coordinating its programs with environmental regulations and green initiatives. Of all the solutions considered, the most effective has been the involvement of robotics, which shows great effectiveness and efficiency in collecting and sorting waste when implemented.

The advancement in modern technology has paved the way for the invention of modern robotics as a tool in combating waste management, which also plays a transformative role in industrialization, which once viewed robotics as a complex tool when it comes to automation. The automation of robotics has been effective in combating waste, while also identifying recyclable products, detecting contaminants, and managing hazardous wastes accurately with almost no room for error (Satav et al., 2023). Collaborative robots, also known as cobots, operated by the introduction of artificial intelligence, have been found to be of great accuracy in identifying recyclables, detecting contaminants, and optimizing waste processing (Olawade et al., 2024). Cobots have been in use in leading technologically advanced societies such as Stockholm, Singapore, and Tokyo, exemplifying the ability of this technology to be used in providing an effective and lasting solution to waste management systems (Zenbird, 2024). As Moncton expresses its need to employ more hands in combating waste management, the adoption of cobots could offer a solution that is scalable, more effective, and meets future demands. However, it is pertinent to note that these cobots alone are not the absolute solution, as there is a need to also integrate this into a larger framework of a smart city initiative to fully maximize its impact and to ensure it tallies with the broader sustainability goals for the long haul. A successful integration comprises a comprehensive approach which includes good data analytics, IoT (Internet of Things) systems, and community engagement to optimize urban services (UNECE, 2024; ITU, 2023).

A smart sustainable city (SSC) is defined as an innovative municipal environment that makes use of modern technology, artificial intelligence, and data-driven feedbacks in order to improve the quality of life while significantly enhancing operational efficiency and ensuring economic, social, and environmental sustainability (UNECE, 2024). An SSC is said to make use of artificial intelligence (AI), data analytics, and the Internet of Things (IoT) to efficiently manage resources like water, energy, and waste (ITU, 2023). Smart waste systems are efficient in reducing landfill overflows, reducing emissions, and enhancing the recycling process, thereby significantly minimizing operational costs (Atofarati et al., 2025).

The goal of Moncton is to become a smarter and more sustainable city that will align with the Canadian national strategy for climatic preservation and digital revolution (Government of Canada, 2019). In the wake of new programs launched in recent years, such as the Smart Cities Challenge launched in 2017, the Canadian government has challenged major cities to make use of data-driven solutions in providing improved services to its populace. Larger urban areas such as Toronto and Montreal, in recent times, have made headlines for employing the use of smart grids and open data platforms, while smaller and mid-sized cities like Moncton have great potential to provide implementable solutions, especially when tailored to fulfil specific targeted purposes (Abbasi et al., 2021).

Across Canada, the use of robotic systems has been employed in urban settlements, especially in areas where there is a need for waste collection and environmental monitoring. Places like Edmonton make use of robotic waste pickers and sensor-enabled waste bins, which enhance accurate collection and sorting (Golubchikov & Thornbush, 2022). Innovations such as these not only improve municipal operations but also help in providing critical data information to track the city's objectives toward climate goals. Moncton has since gained some progress in waste diversion but is still lacking in technological infrastructures and automation, providing a unique opportunity for targeted intervention (FCM, 2023).

The integration of cobots to assist with the sorting of wastes in Moncton helps in improving waste-sorting accuracy and drastically reducing its contamination, which in turn helps to reduce the amount of energy used for each ton of waste that is being processed (Heikkilä, 2020; Lakhouit, 2025). Moreover, this could also be in tune with many of Moncton's environmental key performance indicators (KPIs), which include landfill diversion rates, greenhouse gas emission reductions, and operational energy efficiency. The KPIs mentioned are important to the city's 2020–2030 Community Energy and Emissions Plan (CEEP), which plots Moncton's path toward a greener, low-carbon future (City of Moncton, 2020).

The CEEP's utmost goal in digital transformation is to achieve an eco-conscious development. The various approaches explored include educating the public to actively be involved in its waste sorting, the creation and innovation of more energy management systems, and providing municipal services through data integration and the advent of modern, innovative smart devices (City of Moncton, 2020; Szpilko et al., 2023). Robotics is central to implementing this strategy, as it not only reduces the amount of manual labor required but also produces enough data to help improve and evaluate its performance in real time.

This research focuses on how Moncton can best leverage best practices that enhance robotic technology, particularly in its need to improve the waste management process with the goal of sustaining a more resilient and smart city for the future. This study also examines how cobots can be integrated with the existing modern infrastructure, which efficiently supports accurate waste sorting within a short period of time. To achieve this, this research provides a comprehensive view of what to expect during the implementation of this technology and how it advances a more sophisticated digital culture within its governance while supporting its key sustainability goals.

This study will also serve as a guide for other mid-sized cities on how they can adopt these emerging technologies even with fewer resources or smaller budgets dedicated to such initiatives compared to major urban areas within the country. In providing an analytical approach and results on global best practices, Moncton can reinvent its city to be a template to follow in Atlantic Canada, giving a practical example of how robotics can be integrated to become an integral part of digital transformation while maintaining environmental emissions. Furthermore, beyond its foreseen success in its locality, this research provides additional insight into Canada's national commitment to the 2030 Agenda for Sustainable Development by advancing solutions aligned with the Sustainable Development Goals (SDGs) for urban resilience (Government of Canada, 2015). In pioneering this innovative robotic waste system, Moncton will demonstrate how improved technology, policy, and cooperation from the public can give a more efficient result in creating a cleaner, smarter, and more sustainable environment nationwide.

The research problem addressed in this study is the inefficiency and unreliability of Moncton's current waste sorting system. The objective is to explore the ways in which robotic automation can enhance the efficiency and accuracy of waste sorting in Moncton. This involves identifying necessary infrastructural and policy changes for the successful integration of collaborative robots (cobots). Additionally, the evaluation will focus on how robotic waste sorting can facilitate Moncton's transition into a Smart Sustainable City (SSC).

The research questions addressed are: How can robotic automation improve the efficiency and accuracy of waste sorting in Moncton? What infrastructural and policy adjustments are required for successful cobot integration? How can this innovation support Moncton's transition into a Smart Sustainable City (SSC)?

By examining robotic automation, this study contributes to both academic knowledge and practical solutions. It also provides a template for how mid-sized cities with limited resources can adopt advanced technologies to meet environmental targets. The findings are relevant not only to Moncton but also to other Canadian cities facing similar challenges (Szpilko et al., 2023; Harrison & Donnelly, 2011).

LITERATURE REVIEW

One of the most pressing concerns in modern cities is the management and sorting of waste. With rapid urbanization and population growth occurring alongside limited resources, traditional methods of waste sorting have become increasingly ineffective and tedious (World Bank, 2018; Voukkali et al., 2023). Manual systems are slow, costly, and prone to human error, which often leads to contamination and greater reliance on landfills (Ugwuanyi & Isife, 2017; Garg & Arora, 2025). In response, researchers and policymakers have turned to new technologies such as robotics, artificial intelligence (AI), and smart city frameworks to improve efficiency and sustainability in waste management (Álvarez-de-los-Mozos et al., 2020; Fang et al., 2023; Szpilko et al., 2023).

This literature review examines five key areas relevant to this study:

1. Robotic Waste Sorting
2. Collaborative Robots
3. Artificial Intelligence in Waste Management
4. Smart City Frameworks
5. Waste Management Challenges

Each subsection highlights existing research, practical applications, and research gaps that this study seeks to address.

Robotic Waste Sorting

Global solid waste continues to rise at alarming rates. The World Bank (2018) projected that waste will increase from 2.01 billion tonnes in 2016 to 3.4 billion tonnes by 2050, with urban areas contributing nearly 90% of this growth. Traditional approaches, which rely on manual sorting, are increasingly inadequate for handling such high volumes of waste. They require large numbers of workers, are prone to human error, and often fail to process recyclables effectively.

The emergence of robotic systems offers a promising alternative to these inefficient methods. Robots equipped with mechanical arms, conveyor-integrated vision systems, and smart sensors can identify and sort materials with accuracy rates above 90% (Snoun et al., 2025). These systems reduce contamination, improve recycling rates, and lower operational expenses. Cities such as Helsinki and San Francisco have reported material recovery rates of up to 90% following the implementation of robotic sorting (Ruparel et al., 2024). This evidence suggests that robotic waste sorting is not only feasible but also scalable for mid-sized cities like Moncton.

Collaborative Robots (Cobots)

Cobots, short for collaborative robots, represent a modern generation of machines designed to work efficiently alongside humans. Unlike traditional industrial robots, which are typically large, fixed, and require safety barriers, cobots are smaller, more flexible, and easier to integrate into existing systems. They are built to share workspaces with human operators, making them especially suitable for industries where full automation is either impractical or too costly.

In waste management systems, cobots are trained to recognize items on conveyor belts and sort them into the correct categories. Equipped with sensors and AI algorithms, these systems can detect contaminants, separate recyclables, and handle repetitive tasks with high precision. This innovation reduces the need for manual labor and significantly minimizes human error. Studies have shown that cobots can achieve sorting accuracy rates above 90%, which is far more efficient than manual sorting (Álvarez-de-los-Mozos et al., 2020).

Cobots are already in operation in technologically advanced cities such as Stockholm, Singapore, and Tokyo. These cities have successfully integrated cobots into their waste facilities, improving recycling efficiency and reducing the burden on workers. For example, Singapore's facilities use cobots to separate plastics and metals, thereby reducing contamination and improving recycling rates (Zenbird, 2024). These examples demonstrate that cobots are not just theoretical solutions but practical tools adaptable to different urban needs.

For Moncton, adopting cobots could help address two major challenges: labor shortages and low public participation in waste sorting. By automating much of the sorting process, cobots would reduce reliance on residents correctly separating their waste, while also lessening the workload on facility employees. Cobots provide a scalable solution for mid-sized cities seeking to improve waste sorting efficiency without investing in large, costly industrial systems.

Artificial Intelligence in Waste Management

Artificial intelligence (AI) is the key component of modern technology that makes robotic waste sorting possible. Unlike traditional automation, AI allows machines to learn, adapt, and improve over time. Through machine learning algorithms, cobots can be trained to identify different types of waste materials, detect contaminants, and adjust to changes in waste composition. This makes them more flexible and reliable than manual sorting or outdated mechanical systems.

AI has already been applied in waste management across several cities worldwide. For instance, in Helsinki and San Francisco, AI-powered robots have achieved sorting accuracy rates of up to 98% and improved material recovery rates to nearly 90% (Fang et al., 2023; Snoun et al., 2025). These results show that AI can significantly reduce pollution while increasing recycling efficiency. Another advantage is the generation of real-time data during sorting, which provides valuable insights for municipal planning and sustainability tracking.

AI also integrates seamlessly with other smart city technologies. When combined with Internet of Things (IoT) sensors, AI can monitor waste flows across the city, predict collection needs, and optimize routes for waste trucks, thereby improving overall system efficiency. This reduces fuel consumption, lowers emissions, and enhances service delivery. AI further supports predictive maintenance of equipment, ensuring that robotic systems remain reliable and reducing long-term maintenance costs.

For Moncton, AI offers a way to overcome the limitations of its current three-bag system. Regardless of whether residents sort their waste correctly, AI-powered cobots can identify and separate materials at the facility. This reduces dependence on public participation while ensuring higher recycling accuracy. By adopting AI, Moncton can align its waste management system with broader sustainability goals and position itself among the leading mid-sized Canadian cities implementing advanced waste management technologies.

Smart City Frameworks

The concept of a smart city has gained global interest as urban areas seek ways to improve efficiency, sustainability, and quality of life. Although there is no single definition of a smart city, most scholars agree that smart cities rely on digital technology, automation, and data-driven decision-making to optimize urban services. Cocchia (2014) describes smart cities as environments built around connectivity and sustainability, while Gracias et al. (2023) highlight their role as data-driven ecosystems where artificial intelligence (AI) and Internet of Things (IoT) technologies enable real-time monitoring and optimization of operations.

Smart city frameworks are not limited to new technology alone. Harrison and Donnelly (2011) argue that smart cities also aim to reduce operational expenses, optimize resource use, and improve transparency in governance. In practice, this involves integrating digital tools into everyday municipal services such as transportation, energy, and waste management. Cities like Stockholm, Singapore, and Tokyo demonstrate how smart city initiatives can transform urban living. For example, Singapore's smart waste bins use sensors to monitor capacity and alert collection teams, reducing unnecessary trips and lowering vehicle emissions.

For Moncton, adopting a smart city framework provides a pathway to align its waste management processes with broader sustainability goals. The city's Community Energy and Emissions Plan (CEEP) emphasizes reducing greenhouse gas emissions and improving performance. Robotic waste sorting fits directly into this framework, combining automation with sustainability. By adopting cobots and AI, Moncton can move beyond its traditional manual system and integrate waste management into its smart city strategy.

The literature also points to challenges in implementing smart city frameworks. Kitchin (2013) and Hashem et al. (2016) note that smart cities must balance technological innovation with citizen engagement and inclusiveness. Without public trust and participation, even the most advanced systems may fail to deliver intended results. This highlights the importance of combining robotics and AI with community education and policy support.

In summary, smart city frameworks provide the foundation for integrating robotics into waste management systems. They emphasize not only advanced technology but also sustainability, accountability, and citizen involvement. For Moncton, adopting a smart city approach allows for the implementation of robotic systems that optimize waste sorting and management, contributing to a broader vision of urban resilience and environmental responsibility.

Waste Management Challenges

Despite existing waste management systems, serious challenges persist worldwide. Traditional sorting remains the most common method, but it is slow, labor-intensive, and prone to errors. Employees often struggle to separate recyclables from general waste, leaving contamination rates high. This reduces the quality of recycled materials and increases the amount of waste sent to landfills.

Landfills create further environmental issues. They are a significant source of greenhouse gas emissions, particularly methane, which has substantially greater short-term radiative forcing than carbon dioxide. In Moncton, waste is collected in three separate bags compostables, recyclables, and general waste but public cooperation is inconsistent. Many households fail to sort waste appropriately, meaning improperly sorted bags often end up in landfills. This undermines recycling efficiency while contributing to higher emissions and health risks.

Another major challenge is the time required to process waste. At facilities such as Eco360, waste is often stored before sorting begins. During this period, gases and toxins including bioaerosols and methane are released into the atmosphere. These emissions pose environmental hazards to workers and nearby residents (Garg & Arora, 2025). In addition to these hazards, pests and odors become difficult to control, making waste management less efficient and more costly.

Public participation is also a major concern. Even when cities provide clear instructions for waste disposal, residents do not always comply. This makes it difficult to rely on community cooperation as the main driver of waste sorting. Without stronger systems, urban areas face rising costs, higher emissions, and missed sustainability targets.

These challenges highlight the need for modern approaches. Robotics and AI offer innovative solutions that reduce dependence on manual labor and inconsistent public collaboration. Automated sorting has already improved accuracy, lowered contamination, and reduced emissions in cities where it has been implemented. For Moncton, cobot integration addresses these challenges by improving efficiency, meeting environmental goals, protecting public health, and building robust systems to support future growth.

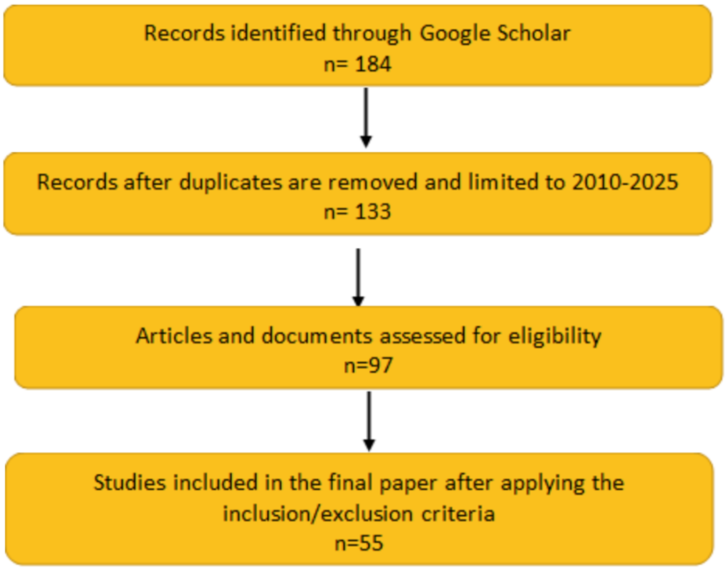
METHODOLOGY

This section describes the chosen research method used to examine the possibility of integrating robots into the city of Moncton's waste sorting system within the scope of a Smart Sustainable City (SSC).

Research structure

This study makes use of qualitative cases for its analysis, which comprises a systematic write-up reviewed and guided by the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The PRISMA approach provides a method that examines the various phases of identifying, filtering, and analyzing scholarly literature to ensure a comprehensive and unbiased synthesis of sources (Page et al., 2021). Using this methodology, this research examined academic journals, municipal policies, and statements to investigate the use of robotics in waste management with a focus on its integration in the city of Moncton, New Brunswick. It also examines how this innovation aligns with the sustainability strategies of the city (Ribeiro, Rezende, Yao, 2019). A summary of the methodological steps is presented in Figure 1.

Figure 1 - Prisma Flowchart



Source: Author

Data collection

Information for this research was primarily collected from a single database, "Google Scholar," due to the limited timeframe. Nonetheless, a comprehensive search to gather data was carried out by reviewing peer-reviewed articles, municipal publications, policy statements, and industry technical documents. The research was narrowed to articles published between 2010 to 2025 and focused on articles with citations. Keywords used as well as combinations including but not limited to: "robots in waste sorting system", "smart cities", "smart sustainable city", "Canada sustainability plan", "waste sorting system in Moncton", "AI AND robots in waste management", "advanced waste sorting systems", "waste management AND Canada".

Data analysis

The data of this descriptive and exploratory study were scrutinized using the four-phase PRISMA framework: identification, screening, eligibility, and inclusion. Documents were chosen based on specific criteria, including whether they were peer-reviewed and related to the research topic. Studies and editorial pieces that didn't have verifiable evidence were excluded.

Reliability and validity

Reliability and validity are vital components when assessing the quality of a research project (Heikkilä, 2020). Reliability is the degree to which a research project is replicable. On the other hand, validity refers to the accuracy or how well the research measures what it is intended to, i.e., adequate information is available to make informed decisions (Andersson et al., 2024).

In qualitative research, reliability is concerned with the credibility of research findings, i.e., data collected, while qualitative validity focuses on ensuring that personal biases or experiences don't affect their viewpoint of the subject being researched (Heale & Twycross, 2015). To ensure validity, an inclusion and exclusion checklist was devised to make decisions on what publications would be included or excluded using some of the keywords stated above as guidelines. Reliability was also enhanced by cross-checking the data for credibility.

RESULTS AND DISCUSSIONS

From the insights of the various articles reviewed, as well as reports, this section enables us to discuss the key points in these findings with an in-depth review of Moncton's waste management system. The main part of this literature is devoted to analyzing how important digitization, AI-powered robots, and other emerging technologies have been in reinventing waste management systems. These articles exemplify how implementing any of these modern innovations has led to increased diversion rates, decreased GHG emissions, and improved operational efficiency. This study also provides insight into how these technologies help support sustainability goals while accelerating the city's transformation toward a Smart Sustainable City (SSC). Robotic systems also generate data that support informed decision-making and further facilitate innovations aimed at creating a Smart Sustainable City.

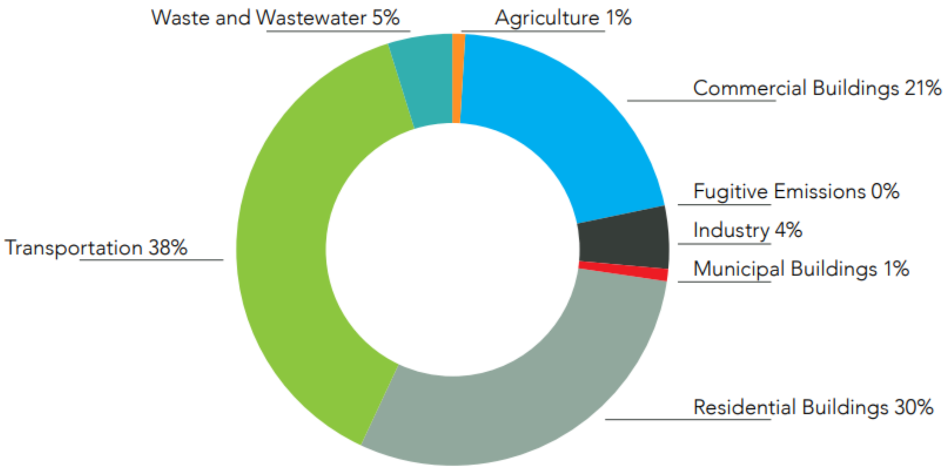
Moncton's solid waste management system

Moncton's waste management system is managed primarily by Southeast Eco360, which serves as the region's waste processing facility. Eco360 operates as one of the largest waste management facilities in New Brunswick and processes about 170,000 tonnes of waste annually. In Moncton, the wastes are collected and transported by Eco360 using trucks. The wastes in blue bags, collected as recyclables, are transported to the recovery facility to be sorted and then recycled into new products. The compostable wastes, often collected in green bags, are moved to the compost facility, where they are screened and sifted for non-compostable materials. The general wastes collected in white bags, which cannot be recycled or reused, are disposed of or directed to landfills (Eco360, 2019).

The bag-sorting system that has been adopted over time often results in sorting inconsistencies, and compliance from the populace remains low, with many of the bags arriving at the facility improperly sorted. This leads to such bags being set aside or even sent to landfills (CBC, 2013). This is why waste remains a major contributor to greenhouse gas (GHG) emissions, estimated at 5% of Moncton's annual municipal emissions (Figure 2). However, this figure also includes methane leakage from landfills and delays in waste-sorting practices.

The sorting of wastes does not occur in real time at the facility; instead, they are collected over an extended period and stored before processing begins— a phase during which gases and other toxic emissions are released, such as bioaerosols, methane, and other GHGs. The delayed sorting also poses health risks due to airborne toxins that are emitted, as well as pests within the environment (Harrison & Donnelly, 2011).

Figure 2 - Moncton's Greenhouse Gas Emissions by Sectors (2022)

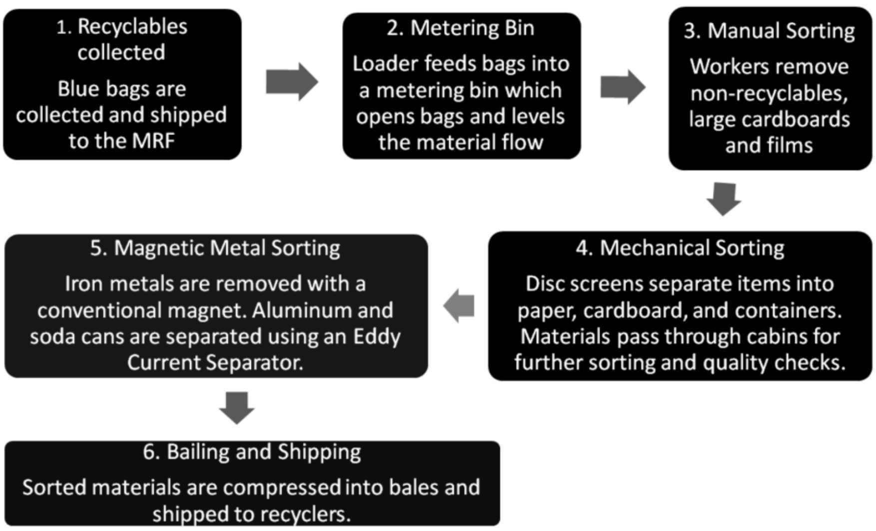


Source: Sustainable Solution Group (2022)

Recycling process

Recycling waste is essential to the planet in preserving its environment and reducing landfill accumulation. According to Eco360, the recycling process in Moncton occurs at the material recovery facility and consists of a team of people who sort out the recyclables received at the facility. An overview of the process is described in Figure 3.

Figure 3 - Moncton's Recycling Process



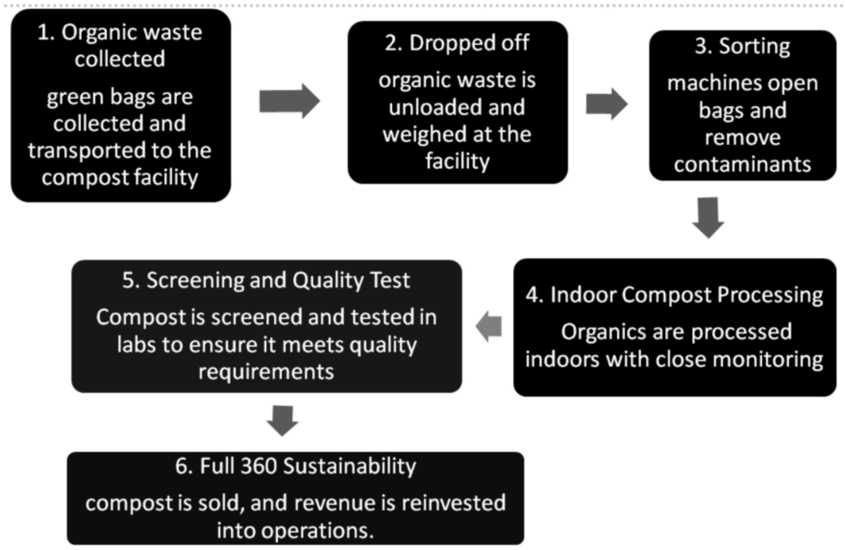
Note: MRF = Material Recovery Facility

Source: Adapted from Eco360 (n.d.-c)

Recycling process

Making compost from waste helps the environment in numerous ways, from not only reducing landfill but also helping plants grow and reducing GHG emissions by absorbing carbon into the soil (Eco360, 2019). In Moncton, at the Eco360 compostable facility, the process, which isn't fully automated, is highlighted in Figure 4.

Figure 4 - Moncton's Composting Process

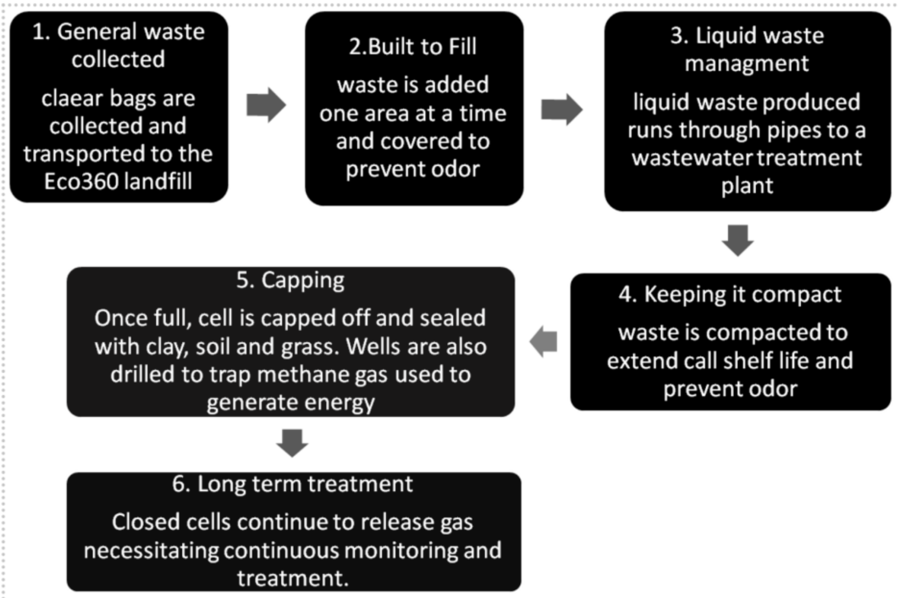


Source: Adapted from Eco360 (n.d.-a)

General Waste Process

General waste is categorized as waste that isn't organic waste and/or recyclables. These wastes often usually end up in landfills. These landfills are not just land with trash piles, instead they are complex systems designed to isolate and reduce the effects of waste on our environment (Eco360, 2019). The landfill is made of cells with waste being pumped into it gradually and compacted to increase longevity and reduce odor. This cell which costs around $1.6 million to build takes about two years to fill, once filled the cell is "capped" with compacted clay and soil to avoid spread of contaminants and then monitored and treated for years as they produce liquid and gaseous by-products. Figure 5 gives an overview of the landfilling process.

Figure 5 - Moncton's Landfill Process



Source: Adapted from Eco360 (n.d.-b)

Automated solid waste management

The invention of robots, particularly AI-powered robots, has demonstrated efficiency and accuracy in terms of their precision in sorting, reducing contamination, and minimizing operational costs. Research has also pointed to the fact that robots are faster in sorting and provide more accuracy, thereby increasing the efficiency of the process. These systems have a 98% waste sorting accuracy rate and improved material recovery rates of up to 90% in cities like Helsinki and San Francisco (Ruparel et al., 2024; Zenbird, 2024; Satav et al., 2023).

Moncton start-up technology

In the heart of Moncton, a local team of scientists is joining forces to develop inventive robotic technology. This system, although originally designed for the manufacturing industry, centers on a collaborative robot (cobot) framework equipped with a two-pronged robotic arm intended to pick, lift, and move heavy objects from one point to another on production lines. However, this technology has the potential to be remodeled for waste management processes.

Presently in its maturity and research-and-development phase, the cobot features adaptable software capable of being used in different industries and integrated with various hardware systems. Within the context of waste management, the robot could be trained through machine learning algorithms to recognize specific waste items on a conveyor belt. By attaching the cobot to existing waste sorting conveyors, it can independently identify, pick, and sort materials into the appropriate streams based on the data it has been fed or sorting algorithms.

Subsequently, in its later development stages, the system would incorporate artificial intelligence for real-time learning and performance optimization, allowing the cobot to adapt dynamically to changes in waste composition, improving its accuracy and efficiency over time.

Incorporating robotics into Moncton's waste system

Moncton's current waste management process, although functional, is still reliant on manual techniques. With a growing population and an increase in waste volumes, the city may face difficulties in achieving its CEEP target of minimizing GHG emissions and no waste being sent to landfill by 2050 if current processes remain unchanged. Robotic automation offers an enhancement to this system.

Robots, AI-powered, can be integrated at key stages of the waste sorting process. For example, in the MRF where recyclables are sorted manually, robots can be used to identify, select and separate materials at a sophisticated speed and accuracy beyond human capabilities. Conversely, at the compost and landfill facility, bags can be scanned, sorted, and separated as most bags arrive at the facility not properly sorted (CBC, 2013). In result, this means fewer materials will end up in landfills which not only means less GHG emissions but also reduced monetary resources and human labor in building and maintaining landfills.

Furthermore, these cobots use machine learning and can identify a wide array of materials, capabilities that might be limited in humans. In cities where such robotic systems have been successfully implemented, an increased diversion rate of 20-40% and a substantial reduction in GHG emissions have been recorded (Ruparel et al., 2024).

Moncton's waste sorting supply chain and robot (cobot) integration

Despite stereotype beliefs that robots are designed to replace the human workforce, integrating robotics into waste management isn't to replace human personnels. Robots complement human roles in the waste sorting supply chain. While cobots perform monotonous tasks, humans remain essential for several purposes (Alvarez-de-los-Mozos & Renteria, 2017). This includes, but not limited to:

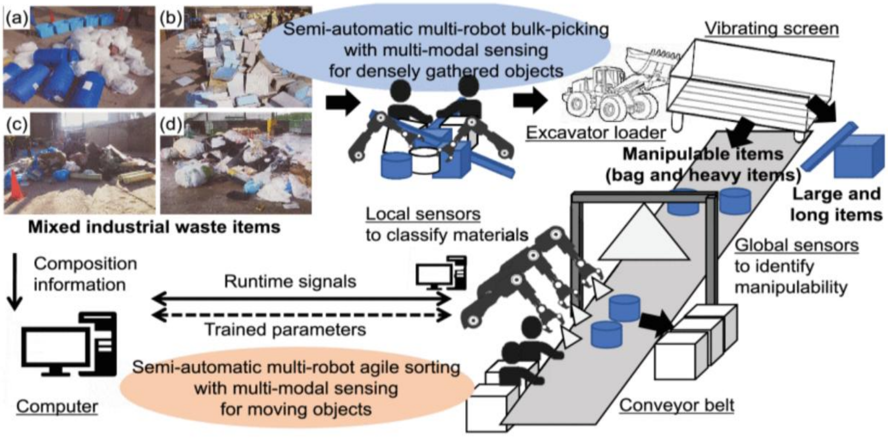
1. Configuring robotic system
2. Feeding waste into robotic systems
3. monitoring robot performance
4. Calibrating sensors and troubleshooting
5. Interpreting and using the data collected

Furthermore, cobots collect data on waste types, volumes, contamination rates, and processing speeds. This data is valuable for municipal reporting, public education, and improving waste policies. Cities like Edmonton have used similar data to optimize collection routes and forecast future waste trends (Golubchikov & Thornbush, 2022).

Robotic sorting workflow

The most popular type of robot employed in waste management is a robotic arm, they are used to pick, sort and separate waste materials. These robotic arms that are usually attached to the waste processing supply chain are equipped with sensors, artificial intelligence (AI) and advanced grippers, suction cups or any form of hand that will facilitate contact with waste materials and aid sorting (Nade & Tone, 2025). Typically, the operation consists of waste being placed on the conveyor in the sorting line with sensors and cameras installed to identify type of waste while the robotic arms selectively grip materials into specific bins. See an illustration of the process in Figure 6.

Figure 6 - Robotic Sorting Workflow



Source: Kiyokawa et al. (2024)

Financial implications and budget impact

Presently, approximately $13 million is allocated by Moncton to waste management (City of Moncton, 2025). Integrating a robotic system could cost between $1.5- $2.5 million dollars depending on the model, infrastructure, and staffing needs. However, research shows that cities typically recoup these costs. For example, as recorded by Jensen, 2022, the Swedish government saved approximately $22,000 monthly after integrating robots into their waste sorting system. Conversely, Satav et al., 2023 also stated that there is return on investment (ROI) in 4–6 years due to savings on labor, contamination fines, and landfill costs. If this is examined carefully, integrating robots will be cheaper than building landfill cells which costs about $1.6 million for one cell. Moncton could also pursue federal funding programs such as Green Municipal Fund (GMF) to offset some of the cost (Green MunicipalFund, n.d.).

Infrastructure, training, and technical requirements

For Moncton to adopt Robotic systems, Eco360 may need to make certain adjustments to facility layouts, primarily conveyors, electrical systems and data centers. Additionally, training will be necessary for operators and maintenance personnel, including technical troubleshooting, data analytics for interpreting system metrics and public education for awareness and sensitization.

Local startups & cost-efficient innovation

Rather than procuring costly robotic systems from international firms, Moncton could collaborate with New Brunswick-based startups to develop or customize cobots. This approach offers several advantages, including cost savings, fostering economic growth, and ensuring in-house technical support.

The University of New Brunswick (UNB), the New Brunswick Innovation Foundation (NBIF), Venn Innovation, and Fredericton's Planet Hatch are examples of institutions that can provide valuable support by working together and collaborating to deliver advanced systems aligned with municipal needs.

CONCLUSION

Moncton, an emerging and growing city, is on its journey to becoming not only a sustainable city but also a smart one. This study explored the potential of utilizing cobots through digital technology, demonstrated by a startup in Moncton, to support its current waste-sorting system. The integration of this technology aligns with the goal of building a smart and sustainable urban center, in harmony with the city's 2050 objective of reducing greenhouse gas emissions and achieving zero waste to landfills (City of Moncton, 2022).

Various studies show that the integration of robots improves waste diversion and enhances operational efficiency. This also provides valuable data to inform critical decisions in policymaking and management. Moreover, positive outcomes have been recorded in cities that have implemented such systems, including Edmonton and Tokyo, setting an example and leading the way as Moncton continues to grow and advance its sustainability agenda (Golubchikov & Thornbush, 2022; Zenbird, 2024).

The latest findings of this research clearly address the questions posed by the research objectives regarding whether these robots can be successfully integrated into Moncton's waste-sorting system, and how best they support its digital transformation and sustainability goals. The results discussed above identify inefficiencies in Moncton's current waste-sorting practices that these cobots can help mitigate or eliminate.

This research also emphasizes the cost-effectiveness of adopting this emerging technology, particularly when developed by local startups, thereby reducing the financial burden. In doing so, robotic sorting uniquely reflects Moncton's environmental KPIs while offering a practical solution that can be implemented within its waste services through digital transformation.

Research implications

From this research, the insights gained can be applied not only in Moncton but also in other mid-sized growing cities with similar circumstances. Moncton serves as a regional prototype for innovation in Atlantic Canada, and if robotic technology is successfully implemented, it could encourage other municipalities to adopt the same approach.

While the use of robots is often associated with large urban centers, this research demonstrates that even smaller cities with limited budgets can participate in digital transformation and drive meaningful change—particularly when these technologies are strategically deployed in targeted areas.

Furthermore, this study contributes to the academic discourse on smart, sustainable cities by offering deeper insight into how robots can be utilized not only to fulfill operational functions but also to support global sustainability frameworks.

Limitations

Projects and research such as this are not without their limitations or constraints. This study is solely based on a single-source literature review conducted within a limited timeframe, which means the data collected was streamlined. The methodology also includes redundant information drawn from publicly available sources, implying that no real-time experiments were performed in the field to generate results.

The assessment of Moncton's current waste management infrastructure further relies on public reports, which may not accurately reflect real-time operational site conditions. It is important to note that, even with these limitations that may render the findings less applicable in certain contexts, the results remain of significant value when interpreted within the appropriate context and supported by relevant data.

Recommendations for future research

This research paves the way for several others. To build upon this study, future research could include pilot testing of the cobot technology at Eco360 to generate real-time performance data and user feedback. An extended study measuring GHG emissions and diversion rates before and after robotic implementation would provide valuable data. Also, it would be beneficial to examine public acceptance and behavioral changes in response to robotic waste systems and the role of digital literacy. Furthermore, an in-depth financial analysis of return on robotic investment for the municipality would be valuable in developing a prototype that can be implemented across cities in Canada.

Integrando a Robótica ao Sistema de Gestão de Resíduos de Moncton: Uma Abordagem de Cidade Inteligente e Sustentável

RESUMO

A rápida urbanização e o crescimento populacional continuam a representar desafios significativos para a gestão eficaz de resíduos sólidos em todo o mundo. Moncton, em New Brunswick, exemplifica uma cidade canadense de médio porte que enfrenta ineficiências em seu sistema de coleta de resíduos, apesar da adoção de uma abordagem de três fluxos. Este estudo explora como a automação robótica, em particular os robôs colaborativos (cobots) alimentados por inteligência artificial (IA), pode aprimorar os processos de triagem de resíduos em Moncton. Orientada pelo framework PRISMA e utilizando uma metodologia de estudo de caso qualitativo, a pesquisa identifica etapas da infraestrutura de resíduos de Moncton que são mais adequadas para a integração robótica. Os objetivos do estudo são três: avaliar a viabilidade da triagem robótica, analisar sua contribuição para as metas de sustentabilidade de Moncton e propor um framework de integração dentro de um modelo de cidade inteligente. Os resultados indicam que a triagem robótica de resíduos pode melhorar significativamente a precisão, reduzir a contaminação e otimizar o uso da mão de obra. Além disso, parcerias locais de inovação têm o potencial de reduzir custos e gerar novas oportunidades de emprego. O estudo conclui que a automação robótica está alinhada com o Plano Comunitário de Energia e Emissões de Moncton (CEEP) e apoia os Objetivos de Desenvolvimento Sustentável do Canadá para 2030. Ele oferece um modelo escalável e sustentável que pode ser replicado por outras cidades de médio porte que enfrentam desafios semelhantes na gestão de resíduos.

PALAVRAS-CHAVE: Triagem robótica de resíduos. Robôs colaborativos. Inteligência artificial. Cidade inteligente. Gestão de resíduos.

REFERENCES

Abbasi, R., Bock, R., & Fernandes, S. (2021). Paving the Way for a Smarter Edmonton: Connecting Buildings to People. ResearchGate. https://www.researchgate.net/publication/356174855

Ahvenniemi, H., Huovila, A., Pinto-Seppä, I., & Airaksinen, M. (2017). What are the differences between sustainable and smart cities? Cities, 60(60), 234–245. https://doi.org/10.1016/j.cities.2016.09.009

AI Singapore. (2025). Transforming waste recycling with multi-spectral AI technologies. https://aisingapore.org/transforming-waste-recycling-with-multi-spectral-ai-technologies/

Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart Cities: Definitions, Dimensions, Performance, and Initiatives. Journal of Urban Technology, 22(1), 3–21. https://doi.org/10.1080/10630732.2014.942092

Alizadeh, T. (2017). Urban Digital Strategies: Planning in the Face of Information Technology? Journal of Urban Technology, 24(2), 35–49. https://doi.org/10.1080/10630732.2017.1285125

Alvarez-de-los-Mozos, E., & Renteria, A. (2017). Collaborative Robots in e-waste Management. Procedia Manufacturing, 11, 55–62. https://doi.org/10.1016/j.promfg.2017.07.133

Alvarez-de-los-Mozos, E., Rentería-Bilbao, A., & Díaz-Martín, F. (2020). WEEE recycling and circular economy assisted by collaborative robots. Applied Sciences, 10(14), 4800. https://doi.org/10.3390/app10144800

Andersson, M., Boateng, K., & Abos, P. (2024). Validity and reliability: The extent to which your research findings are accurate and consistent. ResearchGate. https://www.researchgate.net/publication/384402476_Validity_and_Reliability_The_extent_to_which_your_research_findings_are_accurate_and_consistent

Atofarati, E. O., Adogbeji, V. O., & Enweremadu, C. C. (2025). Sustainable smart waste management solutions for rapidly urbanizing African Cities. Utilities Policy, 95, 101961. https://doi.org/10.1016/j.jup.2025.101961

Carli, Raffaele & Dotoli, Mariagrazia & Pellegrino, Roberta & Ranieri, Luigi. (2013). Measuring and Managing the Smartness of Cities: A Framework for Classifying Performance Indicators. Proceedings - 2013 IEEE International Conference on Systems, Man, and Cybernetics, SMC 2013. 1288-1293. 10.1109/SMC.2013.223

CBC. (2013, October 15). Recycling effort in Moncton eyes apartment dwellers. CBC. https://www.cbc.ca/news/canada/new-brunswick/recycling-effort-in-moncton-eyes-apartment-dwellers-1.2054365

City of Moncton. (2021). Strategic plan 2021–2023: Report to the community. https://www5.moncton.ca/docs/council/Strategic_Plan_2021.pdf

City of Moncton. (2022). COMMUNITY ENERGY AND EMISSIONS PLAN. https://www5.moncton.ca/docs/plans/Community_Energy_Emissions_Plan.pdf

City of Moncton. (2025). Budget Information | City of Moncton. Moncton.ca. https://www.moncton.ca/en/budget

City of Moncton. (2025). Waste Collection. Moncton.ca. https://www.moncton.ca/en/waste-collection

Cocchia, A. (2014). Smart and Digital City: A Systematic Literature Review. Smart City, 13–43. https://doi.org/10.1007/978-3-319-06160-3_2

Das, D. K. (2025). Digital Technology and AI for Smart Sustainable Cities in the Global South: A Critical Review of Literature and Case Studies. Urban Science, 9(3), 72–72. https://doi.org/10.3390/urbansci9030072

Das, D. (2025, July 29). How AI and robotics improve hazardous waste processing in Singapore. Robotics & Automation News. https://roboticsandautomationnews.com/2025/07/29/how-ai-and-robotics-improve-hazardous-waste-processing-in-singapore/93380/

Eco360. (n.d.-a). Compost-can and you can help. https://www.eco360.ca/index.php/compost-can-and-you-can-help

Eco360. (n.d.-b). Landfill: Safe and sound waste management. https://www.eco360.ca/landfill-safe-and-sound-waste-management

Eco360. (n.d.-c). Recycling: A real team effort. https://www.eco360.ca/recycling-real-team-effort

Eco360. (2019). FAQ | eco360. Eco360.Ca. https://www.eco360.ca/faqs

Eco360. (2019). FAQ | eco360. Eco360.Ca. https://www.eco360.ca/recycling-real-team-effort

Envac Group. (2023). Groundbreaking research project 'ReFlow' in waste management at Stockholm Royal Seaport. https://www.envacgroup.com/uk/news/groundbreaking-research-project-reflow-in-waste-management-at-stockholm-royal-seaport

Environment + Energy Leader. (2025). AI waste sorters arrive at San Francisco Ferry Building. https://www.environmentenergyleader.com/stories/ai-waste-sorters-arrive-at-san-francisco-ferry-building,74724

Fang, B., Yu, J., Chen, Z., Osman, A. I., Farghali, M., Ihara, I., Hamza, E. H., Rooney, D. W., & Yap, P. S. (2023). Artificial intelligence for waste management in smart cities: A review. Environmental Chemistry Letters, 21(4), 1–31. https://doi.org/10.1007/s10311-023-01604-3

Federation of Canadian Municipalities (FCM). (2023). Sustainable Communities Progress Report. https://fcm.ca

Garg, S., & Arora, P. (2025). Waste management challenges and opportunities: A holistic approach for sustainable development. International Journal of Environmental Science and Technology, 22, 14753–14770. https://doi.org/10.1007/s13762-025-06653-5

Golubchikov, O., & Thornbush, M. J. (2022). Smart Cities as Hybrid Spaces of Governance: Beyond the Hard/Soft Dichotomy in Cyber-Urbanization. Sustainability, 14(16), 10080. https://doi.org/10.3390/su141610080

Government of Canada. (2015). Taking action on the 2030 Agenda for sustainable development -Canada.ca. Canada.ca.https://www.canada.ca/en/employment-social-development/programs/agenda-2030.html

Government of Canada. (2019). Canada's action on climate change - Canada.ca. Canada.ca. https://www.canada.ca/en/services/environment/weather/climatechange/climate-action.html

Government of New Brunswick. (2024). A Roadmap for Transforming our Waste into Materials for Tomorrow. Retrieved July 9, 2025, from https://www2.gnb.ca/content/dam/gnb/Corporate/Promo/waste-dechets/reports-rapports/solid-waste-management-action-plan-progress-report-2024.pdf

Gracias, J. S., Parnell, G. S., Specking, E., Pohl, E. A., & Buchanan, R. (2023). Smart Cities—A Structured Literature Review. Smart Cities, 6(4), 1719–1743. mdpi. https://doi.org/10.3390/smartcities6040080

Green Municipal Fund. (n.d.). Green Municipal Fund. Greenmunicipalfund.ca. https://greenmunicipalfund.ca/

Harrison, C., & Donnelly, I. A. (2011). A Theory of Smart Cities. ResearchGate, 1. 55th Annual Meeting of the International Society for the Systems Sciences 2011. https://www.researchgate.net/publication/228428752

Hashem, I. A. T., Chang, V., Anuar, N. B., Adewole, K., Yaqoob, I., Gani, A., Ahmed, E., & Chiroma, H. (2016). The role of big data in smart city. International Journal of Information Management, 36(5), 748–758. https://doi.org/10.1016/j.ijinfomgt.2016.05.002

Heale, R., & Twycross, A. (2015). Validity and Reliability in Quantitative Studies. Evidence Based Nursing, 18(3), 66–67. https://doi.org/10.1136/eb-2015-102129

Heikkilä, S. (2020). CIRCULAR VALUE CREATION IN DMR / MSW WASTE MANAGEMENT ECOSYSTEM VIA SMART ROBOTS. https://lutpub.lut.fi/bitstream/handle/10024/161581/ProGradu_Heikkil%C3%A4_Sarianna.pdf?sequence=1&isAllowed=y

ITU. (2023). Smart sustainable cities: Digital transformation for urban resilience. Retrieved from https://www.itu.int/en/mediacentre/backgrounders/Pages/smart-sustainable-cities.aspx

Jensen, H. (2022, March 30). Investing in Fully Automated Robot Waste Sorting Plants - Waste Advantage Magazine. Waste Advantage Magazine. https://wasteadvantagemag.com/investing-in-fully-automated-robot-waste-sorting-plants/

Kamczyc, A. (2021). The crisis in waste management labor. Waste Today Magazine. Retrieved from https://www.wastetodaymagazine.com/news/waste-recycling-hiring-crisis-job-market/

Kaza, S., Yao, L. C., Bhada-Tata, P., & Van Woerden, F. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. In openknowledge.worldbank.org. Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/d3f9d45e-115f-559b-b14f-28552410e90a

Kitchin, R. (2013). The real-time city? Big data and smart urbanism. GeoJournal, 79(1), 1–14. https://doi.org/10.1007/s10708-013-9516-8

Kiyokawa, T., Takamatsu, J., & Koyanaka, S. (2024). Challenges for future robotic sorters of mixed industrial waste: A survey. IEEE Transactions on Automation Science and Engineering, 21(1), 1023–1040. https://doi.org/10.1109/TASE.2022.3221969

Kuljetusrinki. (2024). AI and robots used in waste management. https://helsinkismart.fi/case/ai-and-robots-in-waste-management/

Lakhouit, A. (2025). Revolutionizing urban solid waste management with AI and IoT: A review of smart solutions for waste collection, sorting, and recycling. Results in Engineering, 25, 104018. https://doi.org/10.1016/j.rineng.2025.104018

Lowrie, M. (2023, January 11). Moncton, Halifax top list of fastest-growing urban regions, Statistics Canada says. Thecanadianpressnews.ca. https://www.thecanadianpressnews.ca/atlantic/moncton-halifax-top-list-of-fastest-growing-urban-regions-statistics-canada-says/article_e4f430cb-8fc1-5d31-8ddc-0351bba1528d.html

Nade, T., & Tone, L. (2025). Robots for Waste Management and Recycling. Bio-Robotics, 1(1), 41–54. Retrieved from https://ojs.ukscip.com/index.php/br/article/view/1336

Olawade, D. B., Fapohunda, O., Wada, O. Z., Usman, S. O., Ige, A. O., Ajisafe, O., & Oladapo, B. I. (2024). Smart waste management: A paradigm shift enabled by artificial intelligence. Waste Management Bulletin, 2(2). https://doi.org/10.1016/j.wmb.2024.05.001

Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., & McGuinness, L. A. (2021). PRISMA 2020 Explanation and elaboration: Updated Guidance and Exemplars for Reporting Systematic Reviews. British Medical Journal, 372(160). NCBI. https://doi.org/10.1136/bmj.n160

Ribeiro, S. S., Rezende, D. A., & Yao, J. (2019). Toward a model of the municipal evidence-based decision process in the strategic digital city context. Information Polity: The International Journal of Government & Democracy in the Information Age, 24(3), 305–324. https://doi.org/10.3233/IP-190129

Ruparel, Y., Chaudhary, L., & Rathod, A. (2024). AI-Based Smart Bin for Efficient and Sustainable Waste Classification. World Journal of Environmental Engineering, 9(1), 1–6. https://doi.org/10.12691/wjee-9-1-1

San Francisco Environment Department. (2025). Move over Wall-E: San Francisco partners with Intuitive AI to launch Oscar Sort at the Ferry Building. https://www.sfenvironment.org/press/move-over-wall-e-san-francisco-partners-intuitive-ai-launch-oscar-sort-ferry-building

Satav, A. G., Sunidhi Kubade, Chinmay Amrutkar, Arya, G., & Pawar, A. (2023). A state-of-the-art review on robotics in waste sorting: scope and challenges. https://doi.org/10.1007/s12008-023-01320-w

Snoun, M., Boschetti, G., Fabris, T., & Sinico, T. (2025). Robots for sustainability: Real-time AI-based robotic waste sorting from a moving conveyor. Springer. https://doi.org/10.1007/978-3-031-91151-4_57

Statistics Canada. (2024). The Daily — Canada's population estimates: Subprovincial areas, 2024. Statcan.gc.ca. https://www150.statcan.gc.ca/n1/daily-quotidien/250116/dq250116b-eng.htm

Stockholm Royal Seaport 2030. (2025). Re3 – Increased commitment to waste sorting and reducing energy use. https://www.norradjurgardsstaden2030.se/innovations/increased-commitment-to-waste-sorting-and-reducing-energy-use

Sustainability Solutions Group. (2022). Community energy and emissions plan (Summary report). City of Moncton.

Szpilko, D., Lăzăroiu, G., Nica, E., & Naharro, F. J. (2023). Artificial intelligence in the smart city: A literature review. Entrepreneurial Business and Economics Review, 11(2), 45–61. https://sciendo.com/pdf/10.2478/emj-2023-0028

The World Bank. (2018, September 20). Global Waste to Grow by 70 Percent by 2050 Unless Urgent Action is Taken: World Bank Report. World Bank; World Bank. https://www.worldbank.org/en/news/press-release/2018/09/20/global-waste-to-grow-by-70-percent-by-2050-unless-urgent-action-is-taken-world-bank-report

Ugwuanyi, R. O., & Isife, C. T. (2017). Urbanization and solid waste management challenges in Nigeria. Technoscience Review, 3(1–2), 13–26. https://www.researchgate.net/publication/319448696

UNECE. (2024). Smart sustainable cities: A framework for urban innovation. Retrieved from https://unece.org/housing/smart-sustainable-cities

Voukkali, I., Papamichael, I., Loizia, P., & Zorpas, A. A. (2023). Urbanization and solid waste production: Prospects and challenges. Environmental Science and Pollution Research, 31, 17678–17689. https://doi.org/10.1007/s11356-023-27670-2

Yigitcanlar, T., Kamruzzaman, Md., Foth, M., Sabatini-Marques, J., da Costa, E., & Ioppolo, G. (2019). Can cities become smart without being sustainable? A systematic review of the literature. Sustainable Cities and Society, 45, 348–365. https://doi.org/10.1016/j.scs.2018.11.033

Zenbird. (2024, August 12). AI-powered robot set to improve industrial waste sorting at Tokyo plant | Sustainability from Japan - Zenbird. Zenbird - Gateway to Sustainability in Japan. https://zenbird.media/ai-powered-robot-set-to-improve-industrial-waste-sorting-at-tokyo-plant/

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